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Wind speed analysis in the province of Alicante, Spain. Potential for small-scale wind turbines

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ABSTRACT

The statistical characteristics of the wind speed in the province of Alicante, southeastern Spain, have been analyzed using 9-year wind data recorded at 2 m above the ground by 17 weather stations belonging to the Valencian Institute for Agriculture Research (IVIA). The overall mean wind speed in the area is 1.7 m/s with the windy regions located at the northwest side in the highlands. A clear seasonal and daily pattern is shown with maximum in spring–summer during the central hours of the day, influenced by the sea breeze; and minimum in autumn–winter at night. The wind frequency distributions show two and three modes. The sum-lognormal model is found to be a good fit with very high correlation in all the sites. The extrapolation to 10 m with the power law and the wind shear exponent α, shows a large underestimation in the northern coastal sites and a good agreement in the innermost locations, when compared to measurements done at 10 m in a number of stations.

Contents

1. Introduction

The knowledge of the wind speed in a zone is important for wind energy, loading applications, or pollutant dispersion. In the last years, due to the boom of the renewable energies there has been an increase of wind research. Many studies have been focussed on the estimation of the wind energy potential in different parts of the world like Saudi Arabia [1], Croatia [2], Algeria [3], Mexico [4], Spain [5] or Tunisia [6]. Other studies have done research into the most suitable fitting of wind speed frequency distribution (e.g. [7–10]). Since the available data are measured at altitudes that are not necessarily the same as the hub height of the wind turbine, and the wind profile is influenced by the roughness and atmospheric stability, other studies have addressed vertical profile extrapolation [11–15].

In Spain, the renewable energy sources have been promoted since the application of the Plan for the Promotion of Renewable Energies [16] that set an initial target of generating 12% of total energy consumption from renewable sources by 2010. Specifically in the Valencian region, the Wind Energy Plan for the Valencian Community [17] identified 15 wind energy areas (3 of them located in the Alicante province) and programmed 67 wind farms – the first of these wind farms started in February 2006 – with a total installed power of 2300 MW. However, these studies are not focused on small-scale wind turbines for autonomous applications that require a high level of reliability [18], and they are a real

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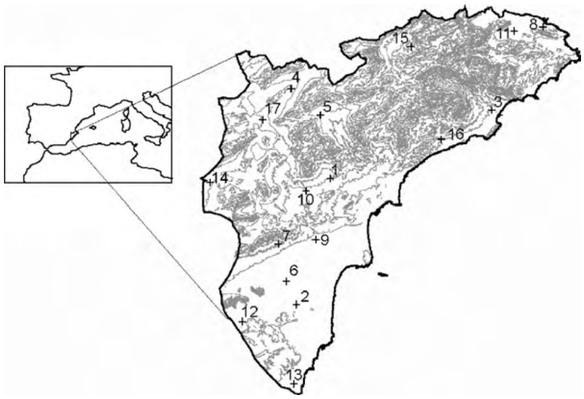

Fig. 1. Topographic map of the province of Alicante. Crosses show the location of the meteorological stations used in this study.

alternative when combined with photovoltaic systems for households and farmhouses that are numerous in the countryside of Alicante.

The aim of this study is to present a wind characterization of the province of Alicante based on the data of 17 stations distributed in the study area, focusing on the wind potential for small-scale wind turbines.

2. Data and methods

2.1. Study area and data set

The province of Alicante is located in the Western Mediterranean Basin, in southeast Spain between 37°51′N and 38°60′N and 1°7′W and 0°15′E (Fig. 1). Its area is about 5.816 km^2 with a quite complex terrain. In the north and northwest the relief is mountainous and the main mountains are the Prebetic ranges where Aitana is the highest peak of the province (1558 m). On the contrary, the terrain in the south side is mostly flat with the Segura and Vinalopó rivers lowland.

We use two sets of meteorological data in this study. The first one is the meteorological data from 17 stations of the high spatial resolution surface network belonging to the Valencian Institute for Agriculture Research (IVIA, http://estaciones.ivia.es) (Table 1). These measurements are half-hourly average observations (with a sampling time of 10 s) of wind speed, wind direction, air temperature, relative humidity and solar radiation recorded at a height of 2 m from January of 2000 to October of 2008. We use this data set for characterizing the winds of the Alicante province.

The second one is 1-year 10 m daily wind speed data from 8 meteorological stations of the Centre for Environmental Studies of the Mediterranean (CEAM, http://www.ceam.es/ceamet/observaciones/ceam/globales/torres_ceam_inicio.html). This data set is used for estimating the errors done when extrapolating the IVIA data to 10 m.

Table 1
Description of the weather stations belonging to the network of IVIA in the province of Alicante.

Stations	Latitude	Longitude	Distance from sea (km)
1-Agost	38°25′40″N	0038′38″W	16.0
2-Almoradí	38°05′27″N	0°46′19″W	11.0
3-Altea	38°36′21″N	0°04′40″W	2.5
4-Camp de Mirra	38°40′47″N	0°46′19″W	43.5
5-Castalla	38°36′21″N	0°40′22″W	31.6
6-Catral	38°09′17″N	0°48′14″W	14.9
7-Crevillente	38°15′25″N	0°49′44″W	21.0
8-Denia	38°49′44″N	0°06′36″E	1.3
9-Elche	38°16′00″N	0°42′00″W	10.9
10-Monforte del Cid	38°23′59″N	0°43′44″W	20.8
11-Ondara	38°49′12″N	0°00′32″E	5.1
12-Orihuela	38°02′52″N	0°57′35″W	24.7
13-Pilar de la Horadada	37°52′26″N	0°47′13″W	2.5
14-Pinoso	38°25′44″N	1°03′36″W	48.2
15-Planes	38°47′09″N	0°21′03″W	27.6
16-Vila Joiosa	38°31′48″N	0°15′21″W	3.5
17-Villena	38°35′48″N	0°52′24″W	43.5

2.2. Wind speed distribution and height extrapolation

In recent years, many research have been done for constructing an adequate model for the wind speed frequency distribution [19–21]. The most commonly used wind speed distribution is the Weibull probability distribution function; however, several authors have shown that Weibull does not fit well when the wind regimes present bimodality [4] or there are calms [7,21].

The sea breeze in Alicante is the most important wind, it blows around 71% of total days [22], and the wind regimes normally present bimodality. In the present study, we use the sum of two lognormal distributions (in some cases three lognormal distributions) to fit the wind speed distribution of the province of Alicante, with the following expression:

$$f(x) = \sum_i \frac{A_i}{w_i\sqrt{2\pi}x} \exp\left[\frac{-[\ln(x/\mu_i)]^2}{2w_i^2}\right] \tag{1}$$

where x is the wind speed, w is a shape parameter related to the width of the distribution, μ is a scale parameter which shows the characteristic value of the wind and A is the amplitude of the distribution; the subscript i refers to each mode. The fitting of the wind speed distributions was performed using Origin v.7, that uses a non-linear least-square minimization technique based on the Levenberg–Marquardt method.

As the meteorological data are measured near the surface and winds increase with altitude, we have to calculate them at turbine hub heights. There are many studies about the vertical wind profiles [11–13], and basically there are two ways for wind height extrapolation: use a power law or employ the logarithmic law [23]. In the present study, we utilize the first one using the expression:

$$V_{10} = V_2\left(\frac{h_{10}}{h_2}\right)^{\alpha}, \tag{2}$$

where V_{10} is the wind speed at the height to be extrapolated (in our case, h_{10} = 10 m), V_2 is the wind speed recorded by the meteorological stations at 2 m from the ground level (h_2), and the power law exponent α is the wind shear exponent. The value of 1/7 is usually used, but research has shown that it depends on the surface roughness, atmospheric stability and height range [13], and values larger than this have been reported [24,25]. Justus et al. [26] estimated an exponent for extrapolating the scale factor of the Weibull distribution, and Manwell et al. [27] used this estimation as the power law exponent with the following expression:

$$\alpha = [0.37 - 0.0881\ln V_2]/[1 - 0.0881\ln(h_2/10)]. \tag{3}$$

Wind speed is recorded with a resolution of 0.1 m/s, therefore the height extrapolation produces "gaps" in the values, i.e. there are values which cannot be obtained like 0, 0.1, 0.3, 0.6, 0.8, 1.1, 1.4... at 10 m height, see Table 2. To prevent this, wind speed values are replaced by numbers of six decimals randomly chosen

Table 2
Example of the extrapolation effect from values measured at 2 m to 10 m with a resolution of 0.1 m/s.

v (2 m)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0...
v (10 m)	–	0.2	0.4	0.5	0.7	0.9	1	1.2	1.3	1.5	1.6...

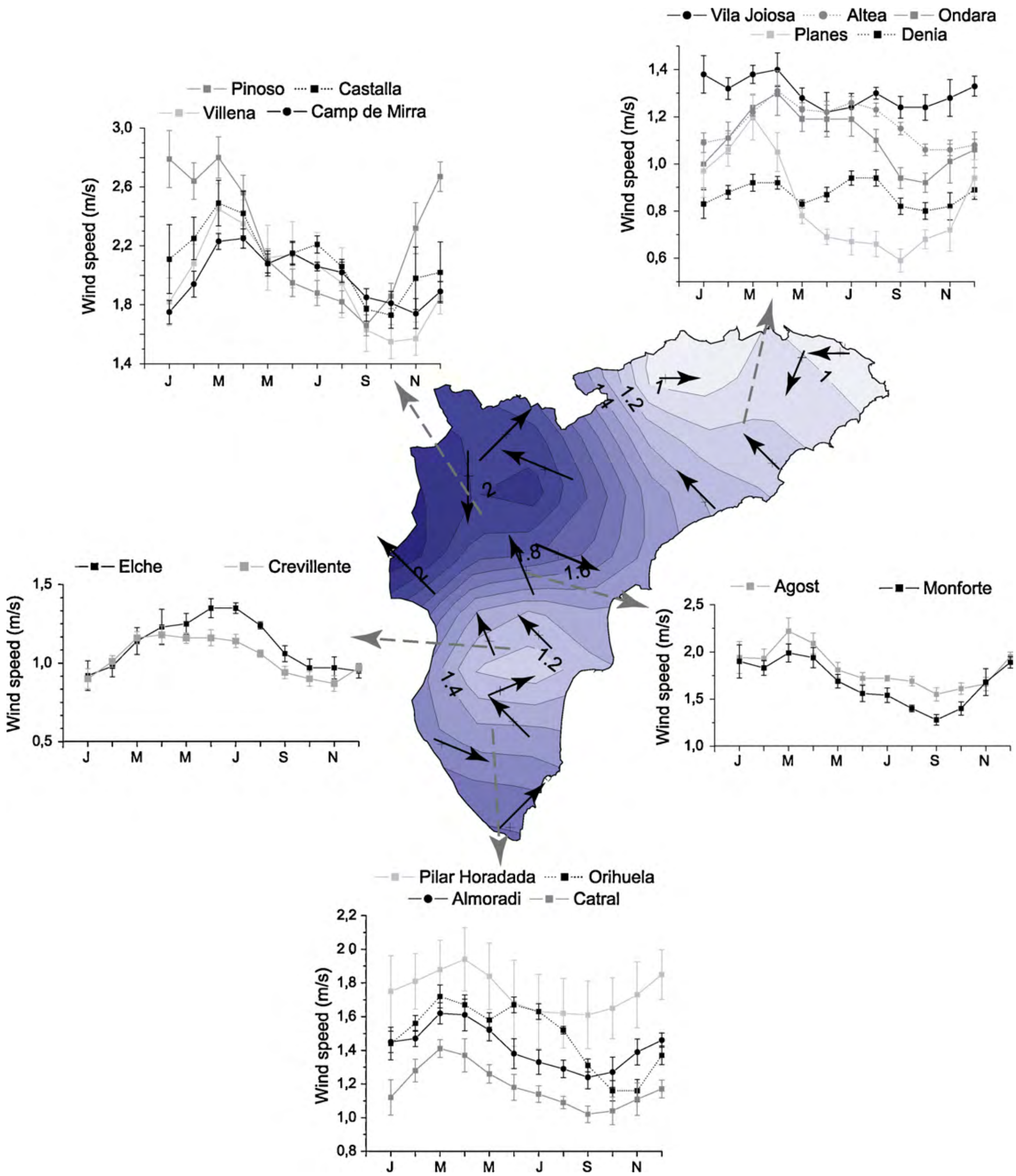

Fig. 2. Map of annual mean 2 m wind speed; arrows indicate the annual prevailing wind direction for each station, and the length arrow is proportional to the wind speed. Graphs show the evolution of the monthly mean wind speed and the standard errors (bars).

within the corresponding wind speed interval. After extrapolating, wind speed is rounded to one decimal place.

3. Results

3.1. Wind speed patterns

As shown in Fig. 2, the area with the strongest winds is located in the northwestern of the province of Alicante coinciding with the highland area, with an annual 2 m wind speeds around 2.1 m/s. On the contrary, light winds flow in the areas next to the coastline placed in the north and the south with annual speeds less than 1.2 m/s.

The seasonal wind speed shows that higher mean values are obtained during the spring for all the meteorological stations except Elche, Crevillente and Denia where it occurs in summer. In turn, minimum mean wind speed values are observed during the autumn, with the exception of Elche and Crevillente where minimum values are recorded in winter.

3.2. Wind speed distribution

The frequency distribution of the wind measured at 2 m for each meteorological station is illustrated in Fig. 3. As seen in this figure, in Almoradí, Catral, Denia, Elche and Pilar de la Horadada, places located in flat terrain, there is a high number of calms (<0.1 m/s). In addition, a bimodal or trimodal distribution is observed in all the study locations. The peak of high winds is due to the summertime sea breeze that induces the seasonal pattern (odd columns in Fig. 3, Fig. 4). Almost all the stations located in the south of the province (except Catral), as well as in Vila Joiosa and Ondara (situated in the north) are best fitted by a sum of three lognormal distributions. The parameters used to model sum-lognormal distribution are reported in Table 3.

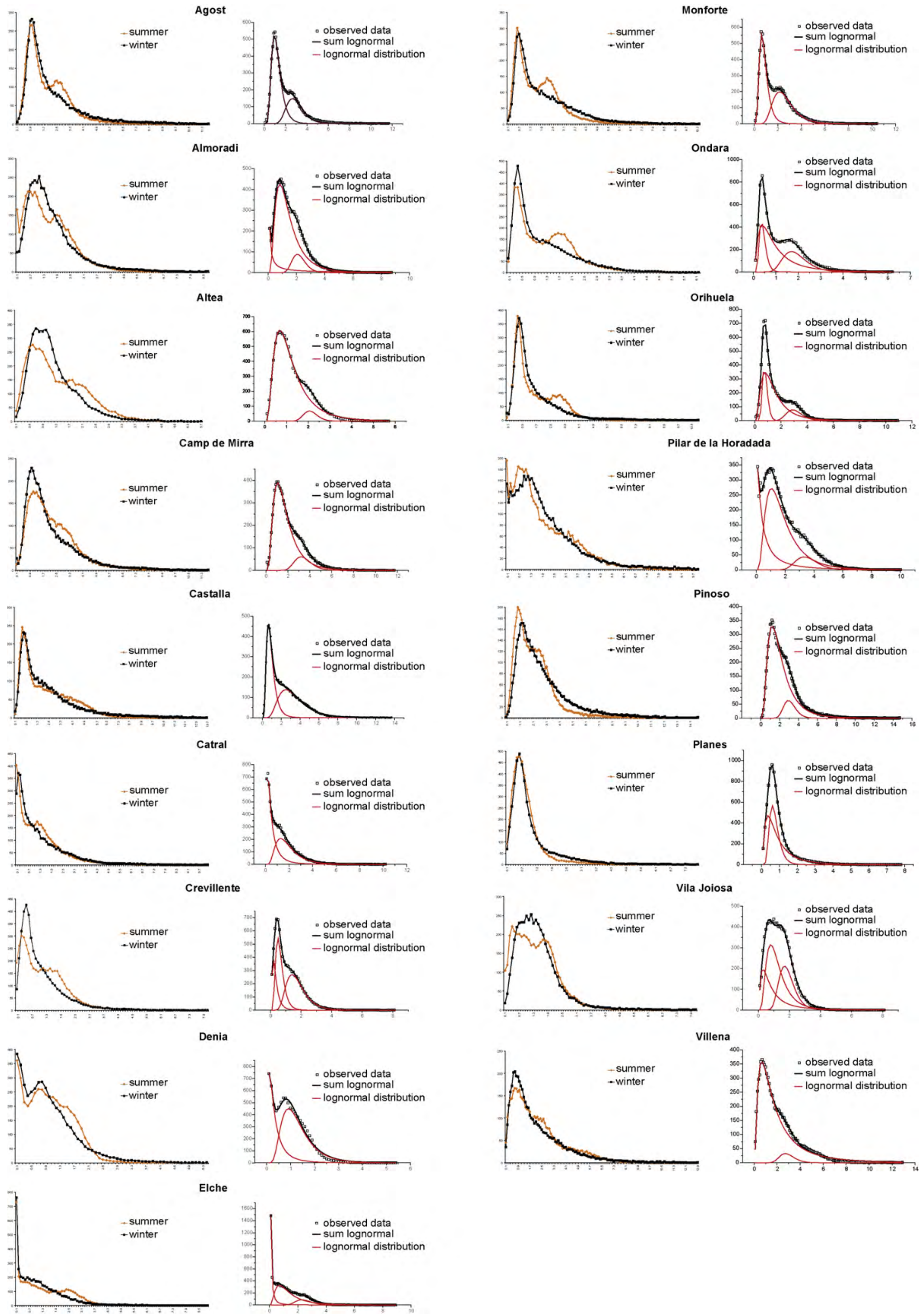

Fig. 3. (Odd columns) seasonal observed 2 m wind speed distribution. (Even columns) sum-lognormal fitting (black line) and single lognormal fits (red lines) for observed data (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

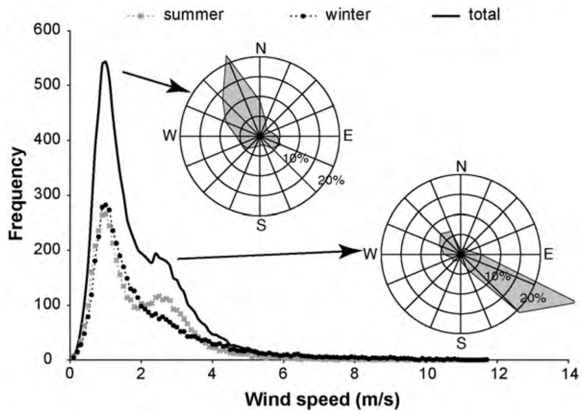

Fig. 4. Observed 2 m wind speed distribution at Agost location (continuous black line). Wind speed distribution in summer and wintertime is shown (dotted line grey and black, respectively). Wind roses for the two wind modes indicate the prevalence of the sea breeze in summertime.

3.3. Vertical extrapolation of wind speed

Wind height extrapolation has been calculated using the power law Eq. (2) together with Eq. (3). The annual mean wind speed at 10 m varies from 1.5 m/s in the north to 3.5 m/s in the northwest, increasing more than 30% the wind speed measured at 2 m height (Table 4). These wind speeds cannot be classified as strong wind, but at the sites located around mountainous terrain more than 30% of annual hours are useful for wind power generation with typical wind turbines like the Bornay 6000 (www.bornay.com) (i.e. hours when wind blows between 3.5 and 14 m/s).

The diurnal evolution of the wind speed extrapolated to 10 m at the study sites is shown in Fig. 5. Note that there are two

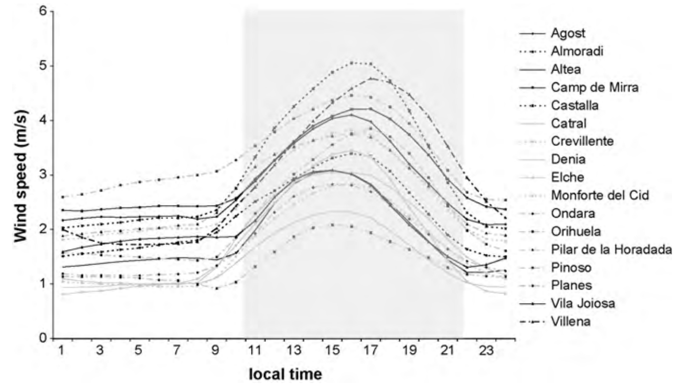

Fig. 5. Diurnal evolution of 10 m wind speed. Grey box indicates winds related with sea breeze.

Table 3
Parameters obtained for the sum-lognormal fitting, for wind measured at 2 m.

Locations	A_1	w_1	μ_1	A_2	w_2	μ_2	A_3	w_3	μ_3	r^2
Agost	566.19	0.42	1.13	285.22	0.28	2.86				0.995
Almoradí	2.12×10^4	390.56	10^{-7}	688.58	0.64	1.24	103.42	0.22	2.16	0.998
Altea	840.54	0.65	1.05	52.90	0.15	2.10				0.995
Camp de Mirra	113.43	0.23	3.38	757.09	0.61	1.54				0.998
Castalla	427.54	0.51	0.84	455.28	0.47	3.13				0.996
Catral	469.79	0.97	0.41	415.28	0.54	1.71				0.999
Crevillente	153.52	0.68	0.29	402.39	0.39	1.65	321.89	0.44	0.59	0.999
Denia	584.00	0.50	1.17	326.65	0.96	0.29				0.993
Elche	118.53	0.23	2.41	540.49	0.73	1.18	2.02×10^5	3.54	1.33×10^{-6}	0.998
Monforte del Cid	450.17	0.46	0.79	416.59	0.36	2.46				0.996
Ondara	153.07	0.35	0.41	499.43	0.85	0.81	236.44	0.29	1.85	0.999
Orihuela	183.44	0.25	0.78	588.43	0.68	1.26	115.76	0.20	3.02	0.999
Pilar de la Horadada	568.84	0.64	1.59	257.31	1.44	0.58	82.17	0.22	3.49	0.997
Pinoso	772.76	0.63	1.81	99.93	0.21	3.07				0.997
Planes	357.93	0.38	0.71	525.44	0.85	0.75				0.9996
Vila Joiosa	254.29	0.27	1.82	217.88	0.94	0.73	417.14	0.56	1.10	0.997
Villena	863.84	0.94	1.59	51.65	0.23	2.86				0.995

Table 4
Statistical characteristics of observed (2 m) and extrapolated (10 m) hourly mean wind speed time series: quartiles, median and useful hours for low-power turbines[a].

	2 m					10 m				
Locations	25%	Median	75%	Mean	Hours	25%	Median	75%	Mean	Hours
Agost	1.0	1.5	2.6	1.9	10%	1.6	2.4	3.8	2.9	30%
Almoradi	0.8	1.3	2.0	1.5	4%	1.3	2.1	3.1	2.3	17%
Altea	0.7	1.1	1.7	1.2	1%	1.2	1.8	2.7	2.0	9%
Camp de Mirra	1.1	1.7	2.8	2.1	13%	1.8	2.7	4.1	3.1	34%
Castalla	0.8	1.7	3.2	2.2	20%	1.4	2.7	4.7	3.3	38%
Catral	0.4	1.0	1.8	1.3	5%	0.7	1.6	2.8	2.0	15%
Crevillente	0.5	0.9	1.6	1.1	1%	0.8	1.5	2.5	1.8	9%
Denia	0.4	0.9	1.4	1.0	0%	0.8	1.5	2.2	1.5	3%
Elche	0.3	1.1	1.9	1.2	2%	0.6	1.6	3.0	1.9	16%
Monforte del Cid	0.8	1.4	2.5	1.8	9%	1.3	2.3	3.7	2.7	28%
Ondara	0.5	0.9	1.7	1.2	2%	0.8	1.6	2.7	1.9	11%
Orihuela	0.8	1.2	2.2	1.6	6%	1.3	1.9	3.3	2.4	23%
Pilar de la Horadada	0.8	1.5	2.6	1.8	13%	1.4	2.4	3.9	2.8	30%
Pinoso	1.3	2.0	3.0	2.4	17%	2.0	3.1	4.5	3.5	41%
Planes	0.5	0.7	1.1	0.9	1%	0.9	1.2	1.8	1.5	5%
Vila Joiosa	0.8	1.3	1.9	1.4	2%	1.3	2.1	2.9	2.2	11%
Villena	0.9	1.6	2.8	2.1	16%	1.4	2.5	4.2	3.1	34%

[a] Bornay 6000 wind turbine (www.bornay.com).

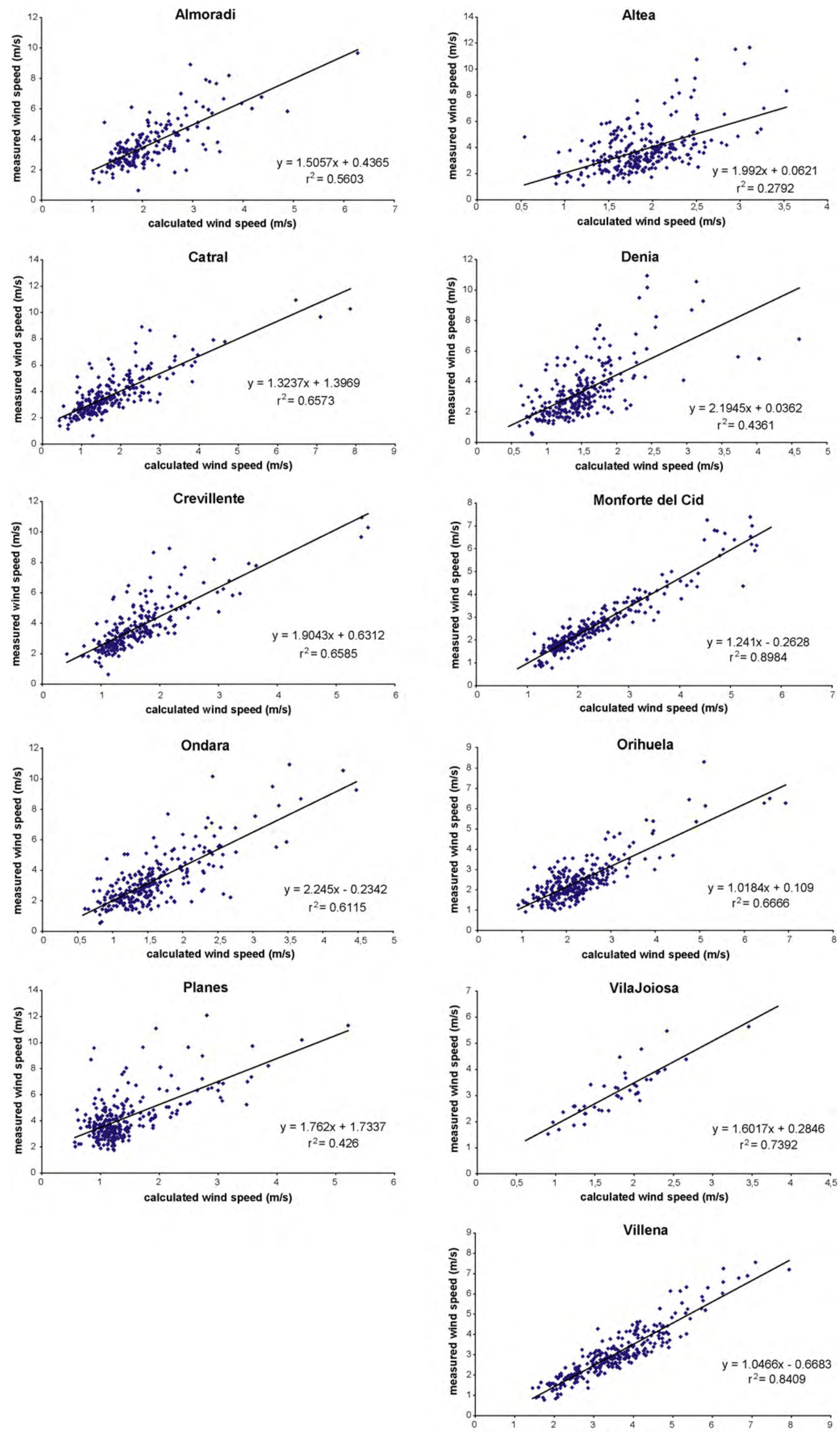

Fig. 6. Comparison between daily wind speed extrapolation and daily wind speed measurements. Graphs on the left compare 10 m data of stations located near the study sites; graphs on the right compare 10 m data of stations located in the same place than the study site.

differentiated parts: one related to light winds, with mean wind speed of 1.7 m/s; and a second one related to moderate winds that correspond to the sea breeze hours, as Azorín-Molina et al. have pointed out [28], with an average wind of 2.9 m/s.

Since the vertical extrapolation is based on Eq. (2), which depends on an empirical parameter (α), a comparison with daily 10 m wind speed measurements from weather stations located next to the study sites is done. Eleven of the seventeen stations were compared with measured wind speed data. In some cases as Planes, Altea and Denia the determination coefficient is not significant ($r^2 < 0.5$) (Fig. 6), but in all the cases the extrapolated values underestimate the daily measured wind speeds. Calculated values range from 98% of the measured data in the innermost stations, to 45% in the stations located in the north at the coastline. The worst height extrapolation occurs in this area since the wind shear coefficient, α, depends on roughness and stability conditions; both parameters present high spatial and temporal variations in places with very complex terrain with high, rocky cliffs typical of the north coast of Alicante.

4. Conclusion

In this paper we present a study of 9-year winds in the province of Alicante. The study area is affected by light winds in the northern coastline and the south, and moderate ones in the northwestern, with a mean value for the whole province around 1.7 m/s measured at 2 m above the ground. As the area is affected by the sea breeze, there is a clear diurnal pattern with a peak in the afternoon (around 16 h local time). A seasonal variation is also pointed out with maximum in spring and summer, and minimum in winter and autumn.

The wind speed frequency distributions of all the meteorological stations show a multimodal pattern and a high number of calm hours; they are modelled by a sum of lognormal distributions that provides very good fit with $r^2 > 0.99$.

A vertical extrapolation to 10 m has been calculated with the power law and the α coefficient from the literature. A comparison of daily averages of the extrapolated data and measured wind speeds shows a strong underestimation at the northern coastline and good agreement in the innermost locations. The area's potential for small-scale turbines is limited and hybrid systems should be considered.

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